ADVANCED COMMUNICATION ARCHITECTURES AND TECHNOLOGIES FOR MISSIONS TO THE OUTER PLANETS

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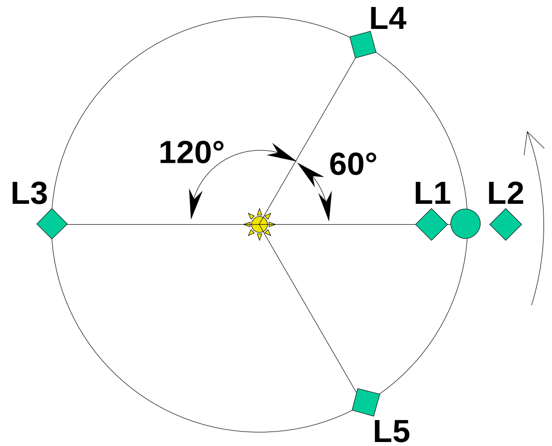
Communication Needs for the Outer Planetary missions

- **High rate data movement**
  - Data Rate to Europa
- **Full coverage of Europa missions**
  - Not possible now with one Communications Orbiter
- **Small Earth ground station antennas**
  - 10-20M class antennas connect to space network relay stations
- **Internet compatible space network**
  - Internet capabilities
  - Enables autonomous operations
- **A means to assist in navigation and timing**
  - To support a spacecraft's autonomous navigation
  - To synchronize measurements across the solar system

Outer Planet Communication Network Architecture Concept



- For this presentation we have looked at relay stations at the Lagrangian points of planets.
- Other concepts with relay stations in intermediate sun orbits should work also.
- Relay stations provide a solar system network.
- Relay stations also serve as lighthouses to support autonomous navigation.

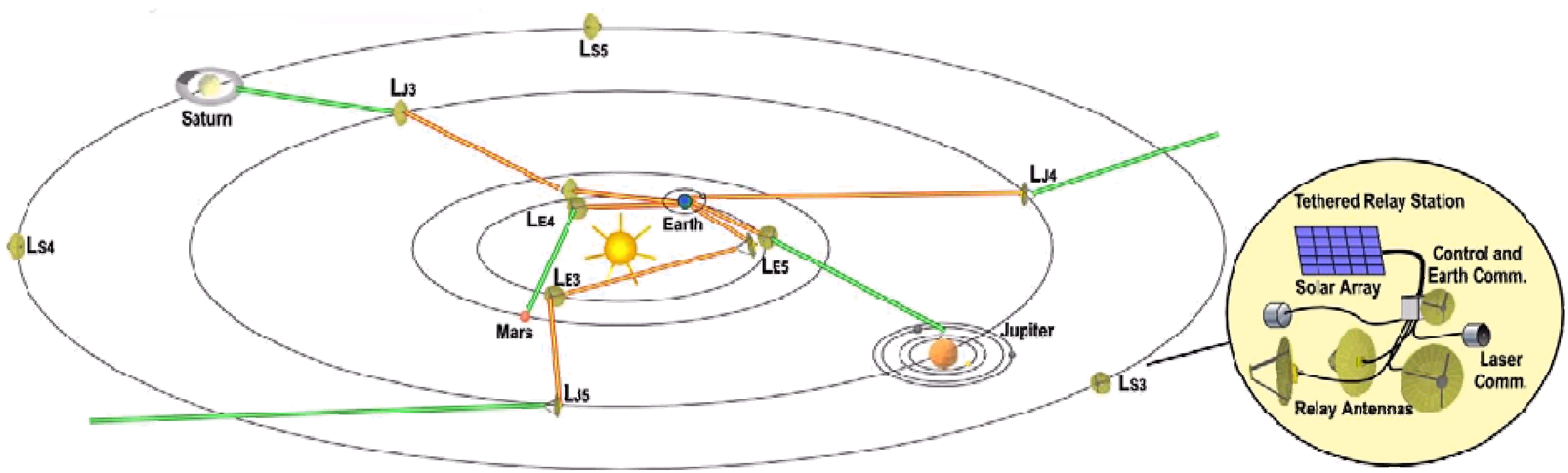
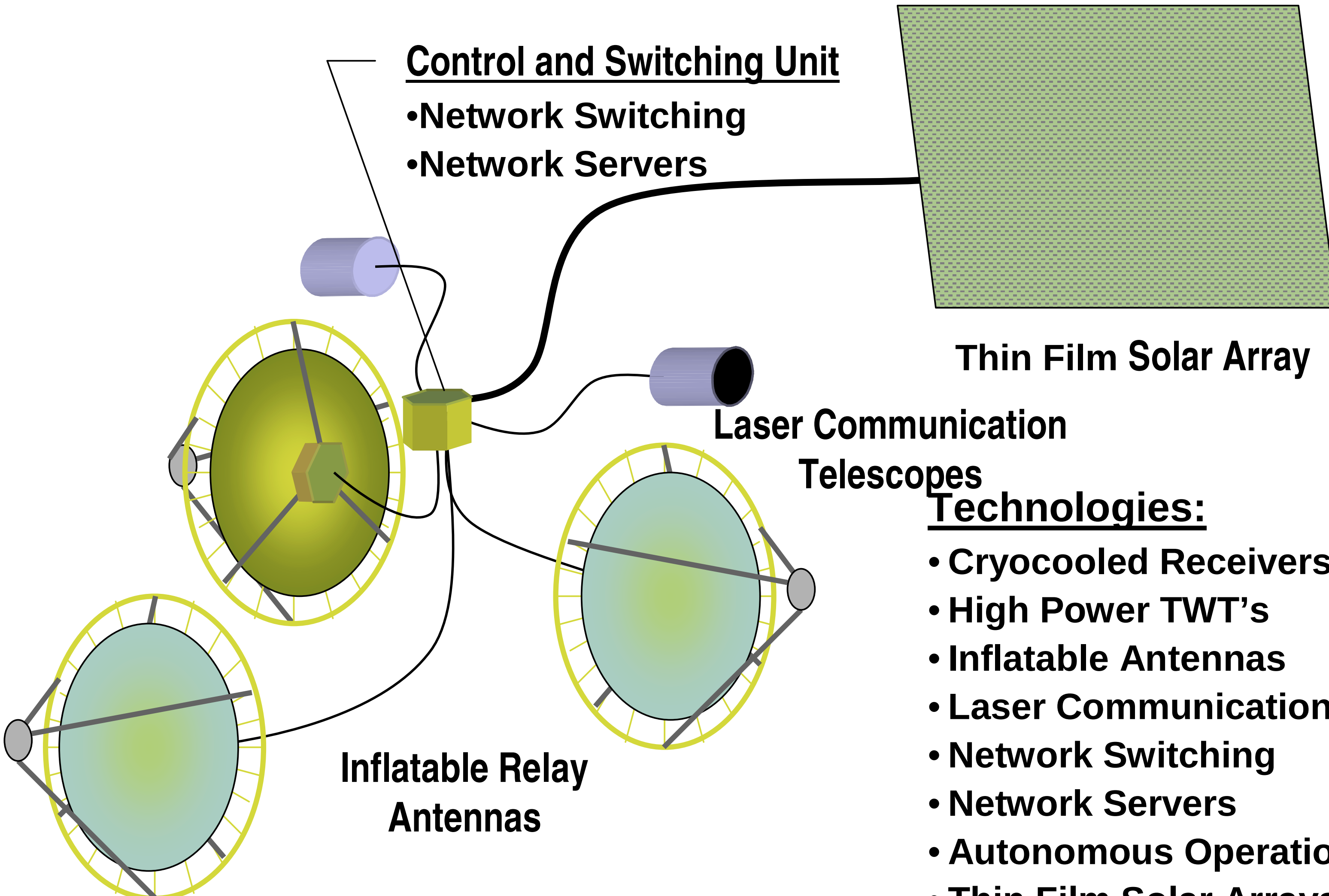


Figure 1, Outer Planet Relay Network

Relay Station



Technologies:

- Cryocooled Receivers
- High Power TWT's
- Inflatable Antennas
- Laser Communications
- Network Switching
- Network Servers
- Autonomous Operations
- Thin Film Solar Arrays

Relative Link Data Rates

Spacecraft at 3W transmit and 1m dia. Antenna		Max Link (AU)	S-band	X-band	Ka-band
RF Frequency (GHz)			**2.295**	**8.425**	**32**
Baseline Link (bps)	Spacecraft to 34m	1	1,000	13,476	68,046
	Spacecraft to 20m relay	1	346	4,663	50,450
Earth - Mars	Direct	2.52	157	2,122	10,715
Earth - 1 or 2 Relays - Mars	E-Le45-(Le3)-M	1.732	115	1,554	16,818
Earth - Jupiter	Direct	6.2	26	351	1,770
Earth - 2 Relays - Jupiter	E-Le45-Lm345-J	3.96	22	297	3,217
Earth - Saturn	Direct	10.54	9	121	613
Earth - 2 or 3 Relays - Saturn	E-Lm345-Lj345J-S	5.67	11	145	1,569
Earth - Uranus	Direct	20.19	2	33	167
Earth - 2, 3, or 4 Relays - Uranus	E-Lm345-Lj345J-Ls345-U	11.93	2	33	354
Earth - Neptune	Direct	31.06	1	14	71
Earth - 2, 3, or 4 Relays - Neptune (Via Saturn L-point Relays)	E-Lm345-Lj345J-Ls345-N	22.32	1	9	101

Very High Rate Relay Links to Earth

Spacecraft at 30W transmit and 3m dia. Antenna		Max Link (AU)	S-band	X-band	Ka-band
RF Frequency (GHz)			**2.295**	**8.425**	**32**
Baseline Link (bps)	Spacecraft to 34m	1	90,000	1,212,878	6,124,140
	Spacecraft to 20m relay	1	31,139	419,644	4,540,486
Earth - Mars	Direct	2.52	14,172	190,992	964,371
Earth - 1 or 2 Relays - Mars	E-Le45-(Le3)-M	1.732	10,380	139,890	1,513,584
Earth - Jupiter	Direct	6.2	2,341	31,552	159,317
Earth - 2 Relays - Jupiter	E-Le45-Lm345-J	3.96	1,986	26,760	289,542
Earth - Saturn	Direct	10.54	810	10,918	55,127
Earth - 2 or 3 Relays - Saturn	E-Lm345-Lj345J-S	5.67	969	13,053	141,233
Earth - Uranus	Direct	20.19	221	2,975	15,024
Earth - 2, 3, or 4 Relays - Uranus	E-Lm345-Lj345J-Ls345-U	11.93	219	2,948	31,902
Earth - Neptune	Direct	31.06	93	1,257	6,348
Earth - 2, 3, or 4 Relays - Neptune (Via Saturn L-point Relays)	E-Lm345-Lj345J-Ls345-N	22.32	63	842	9,114

Continuous Coverage Communication Architecture - Mars Missions

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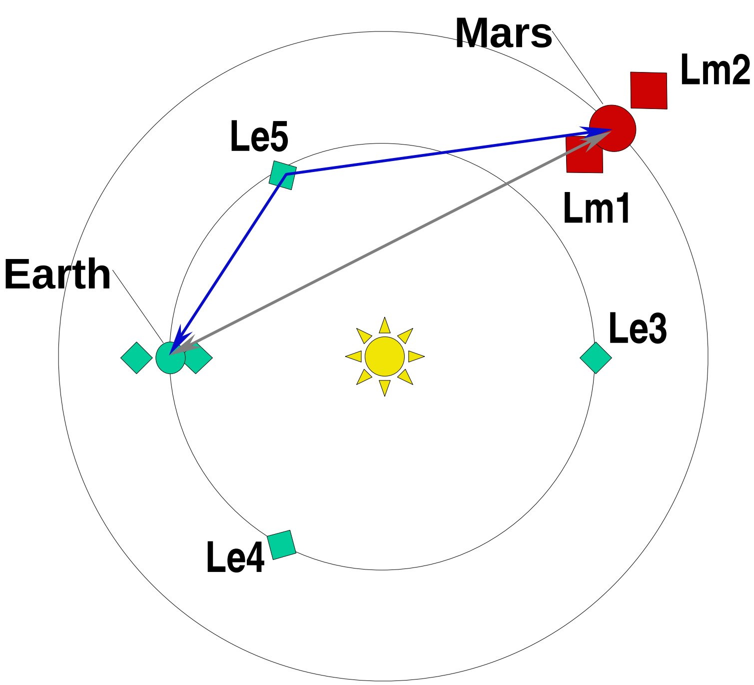
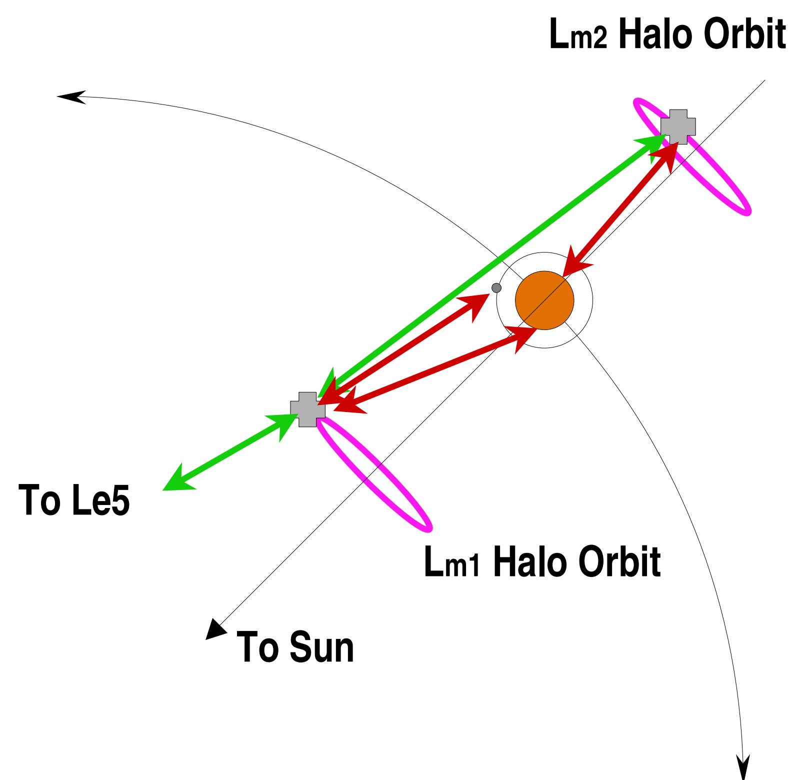
Utilize Mars Lm1 and Lm2 points



Relay stations are placed at the Earth Lagrangian points

A relay at Lm2 continuously observes dark side of Mars



A relay at Lm1 enables very high data rates from Mars to the space network

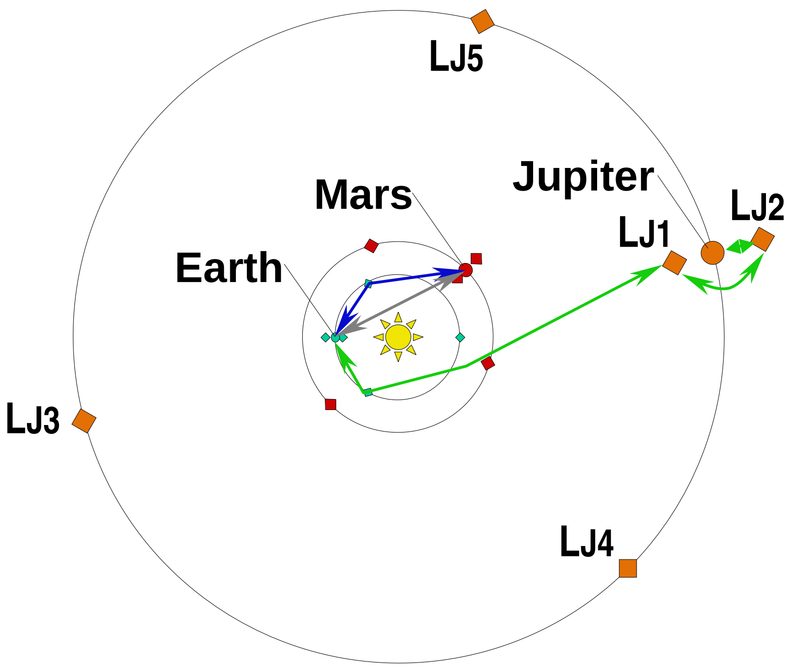
Continuous Mars Service Enabled by In-Space Relay Network

Spacecraft at Mars with 3W 1m dia. transmitting antenna and 30W 3M dia. transmitting antenna		Max Link (AU)	Bit Rate at Ka-band
M to Earth (Sun-Mars conjunction data lost)	Small science S/C to 34m	2.52	10,715
M to Earth (Sun-Mars conjunction data lost)	Large science S/C to 34m	2.52	964,371
M to Earth (Sun-Mars conjunction data lost)	Small science S/C to 70m	2.52	38,931
M to Earth (Sun-Mars conjunction data lost)	Large science S/C to 70m	2.52	3,503,769
Le4 or Le5 to Earth	Relay to 34m	1	1,134,100,053
Le4 or Le5 to Le3	Relay to relay	1.732	280,317,991
Le345 to Lm1 Halo Orbit	Relay to relay	0.82	1,250,601,780
Halo Orbit Lm2 to Halo Orbit Lm1	Relay to relay	0.014492	4,004,184,831,912
M to Halo Orbit Lm1 (front Side), Lm2 (back sid	Small science S/C to relay	0.007246	961,004,360
M to Halo Orbit Lm1 (front Side), Lm2 (back sid	Large science S/C to relay	0.007246	86,490,392,369

Relay spacecraft has 20m antenna, 100W transmit power.
Small science spacecraft has 1m antenna, 3W transmit power.
Larger science spacecraft has 3m antenna, 30W transmit power.

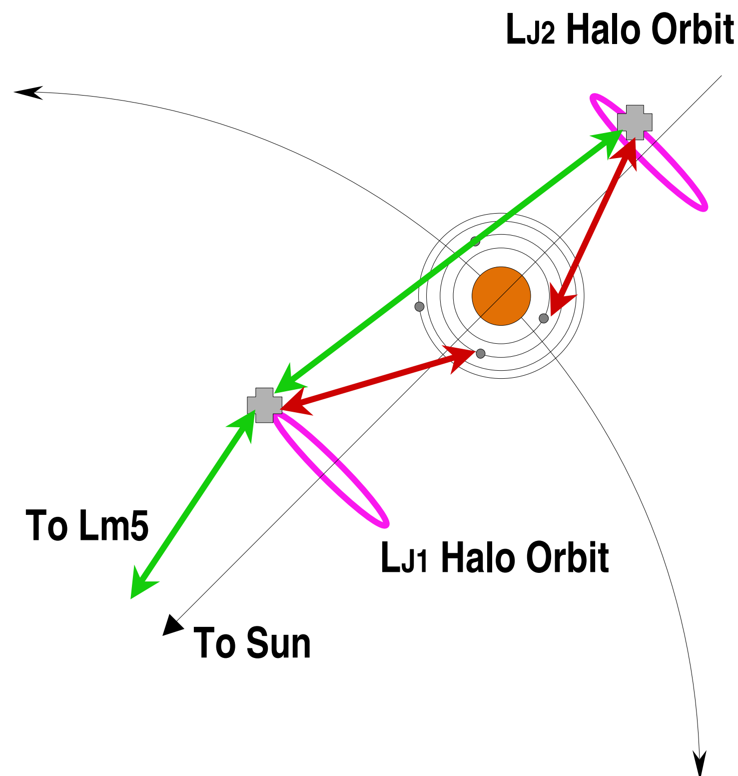
Continuous Coverage Communication Architecture - Jupiter Missions

Utilize Jupiter's L_{J1} and L_{J2} points



Relay stations are placed at the planetary Lagrangian points

A relay at L_{J2} continuously observes dark side of Jupiter



A relay at L_{J1} enables very high data rates from Jupiter to the space network

Continuous Europa service enabled by in-space relay network

Spacecraft at Europa with 3W 1m dia. transmitting antenna and 30W 3M dia. transmitting antenna		Max Link (AU)	Bit Rate at Ka-band
J to Earth (Sun-Mars conjunction data lost)	Small science S/C to 34m	6.2028	1,769
J to Earth (Sun-Mars conjunction data lost)	Large science S/C to 34m	6.2028	159,173
J to Earth (Sun-Mars conjunction data lost)	Small science S/C to 70m	6.2028	6,426
J to Earth (Sun-Mars conjunction data lost)	Large science S/C to 70m	6.2028	578,310
Le4 or Le5 to Earth	Relay to 34m	1	1,134,100,053
Le4 or Le5 to Le3	Relay to relay	1.732	280,317,991
Le345 to Lm345	Relay to relay	0.86	1,136,972,197
Lm345 to Lj1 Halo Orbit	Relay to relay	3.96	53,623,650
Halo Orbit Lj2 to Halo Orbit Lj1	Relay to relay	0.72	1,622,115,426
J to Halo Orbit Lj1 (front Side), Lj2 (back side)	Small science S/C to relay	0.36	389,308
J to Halo Orbit Lj1 (front Side), Lj2 (back side)	Large science S/C to relay	0.36	35,037,693

Relay spacecraft has 20m antenna, 100W transmit power.
Small science spacecraft has 1m antenna, 3W transmit power.
Larger science spacecraft has 3m antenna, 30W transmit power.

Ka-Band High Efficiency Miniature TWT

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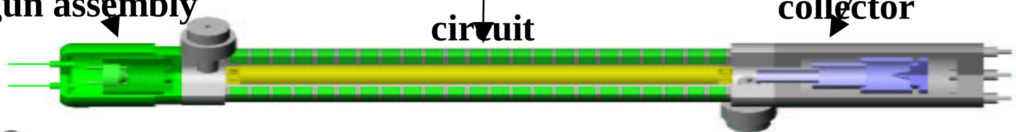
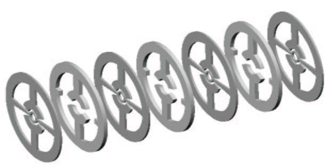
Expected Performance:

- Frequencies of interest: 32 & 26.5 GHz
- RF output power: 10-20 W
- Overall efficiency: 50-60%
- Potential for more than 1/3 reduction in length
- Potential for 50% reduction in power system mass

Design:





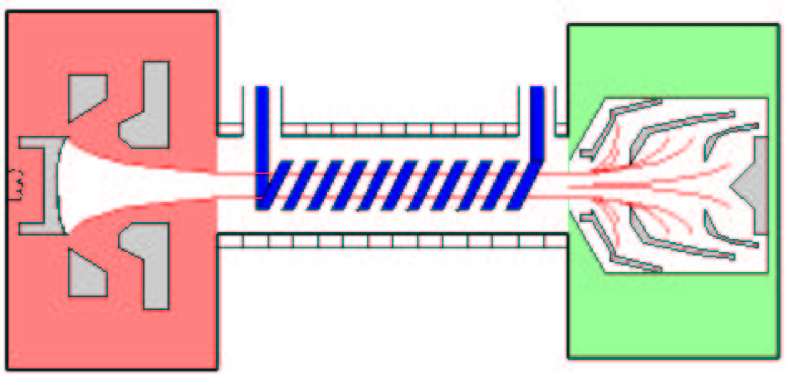
Exploded view of circuit and spacer disk elements

Segment of RF circuit

- Novel “finned ladder” RF circuit design
  - –Stacked disks with alternating geometry

Expected time frame at TRL4 or 2003

Space Communications
Constant Efficiency Traveling Wave Tube



Product Objectives

Prototype a 32 GHz Traveling Wave Tube while demonstrating variable power, 30 to 100 watts and near-constant efficiency, >50% for upcoming deep space communication missions preferably to Mars. The expected increase in data rate is several times that of the current state of the art.

Participants & Customers

- **Principle Investigator**
  - Dr. James Dayton, Hughes Electron Dynamics
- **Impact on Enterprise Customers:**
  - Enables high capacity link to return science data and video from Mars orbiter to Earth
  - Wide range of output power at high efficiency enables flexibility to change power allocations over life of mission

Product Schedule & Funds

Product Milestones	01	02	03	04
Complete the design of gun, collector, coupler, etc.	▲			
Fabricate the prototype TWT.		▲		
Optimize for the final design.			▲	
Fabricate and test the 100W TWT.				▲
CETDP ($K)	**610**	**610**	**610**	**130**
TOTAL ($K)	**460**	**610**	**610**	**130**

High Temperature Superconductivity Technology Development for Space Communications

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- Objectives
  - –Develop viable HTS RF Space Flight Qualifiable Comm. subsystems integrated with highly reliable, compact cryocoolers
  - –Demonstrate advantages for HTS subsystems (mass/size reduction, cost savings, performance discriminators) including overhead of cryocooling subsystem

DuPont
HTS Material Processing/ Filter Packaging

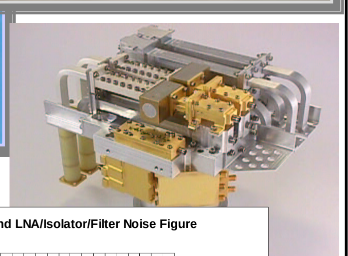
ComDev
System/Filter Design; Packaging/ I&T; Flight Qual

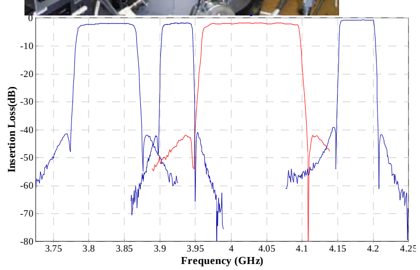
LMSS-ATC
Cryocooler Devel; Thermal;Cryogenic Packaging

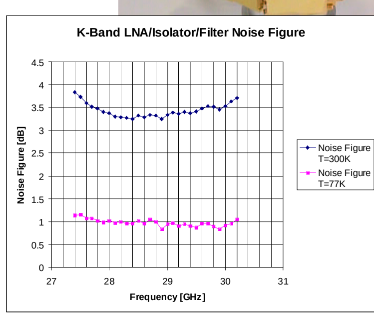
DARPA TRP Program
(50/50 Cost Share)

Integrated HTS Flight Qualifiable Subsystems

LMSS-CPC
Systems Engineering; End User Perspective







- **Accomplishments Summary**
  - Compact, efficient Pulse Tube Cryocooler development **(1-3.2W cooling, <23W/W; 3 Kg; Eff. Electronics Controller-1.7Kg; 93% eff.; .98 rel @ 10years)**
  - Subsystem #2: Cryogenic Integrated Ka,C band Receiver/HTS Filter EM **(cryogenic Ka LNA, HTS C-band IFA/LNA; up to 2dB reduction in receive noise)**
  - Low thermal loss, low RF loss C and Ka band transitions

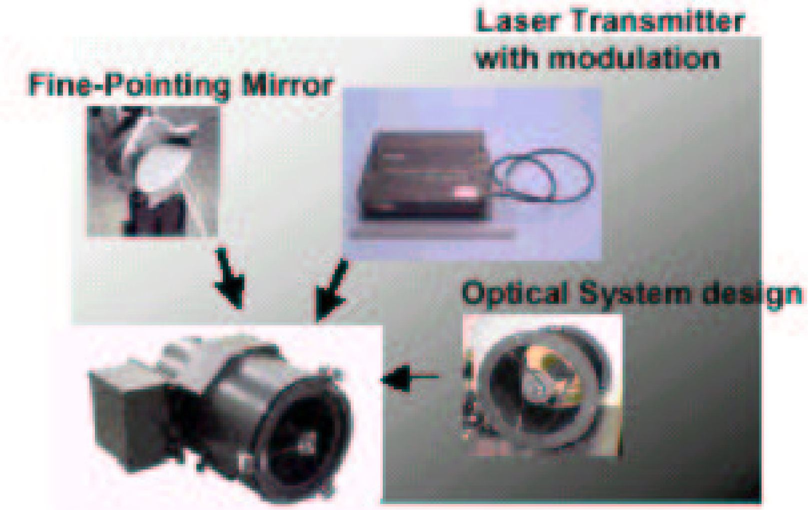
Inflatable Antenna

14 – meter – diameter inflatable antenna

Optical Communication

Objective :

Design and prototype component level technologies that constitute an optical communications terminal, emphasizing high efficiency operation.



Develop and validate a complete set of acquisition, tracking and pointing (ATP) technologies with < 1 μrad pointing accuracy for laser communication throughout the solar system. Specific products are Advanced Algorithms, Laboratory Validated Algorithms, Critical Components Testing/ Characterization (Focal Plane Arrays, Inertial Sensors; Accelerometers, Gyros, Rate Sensors). Sub- micro- radian Pointing System and laboratory validated hardware.

Development and Validation is underway.

Conclusions

- An in-space relay station network infrastructure placed at the planetary Lagrangian points will provide:
  – High data capacity and rates.
  – Continuous coverage of Jupiter vicinity missions.
  – Service several missions simultaneously.
- Reduces Earth ground station service time.
- Relay station infrastructure enables autonomous missions by being navigational lighthouses.
- Ka-band high power transmitters and ultra low-noise receivers, lightweight antennas, and optical communication link technologies are being pursued to enable the relay concept as well as enhance the direct links.